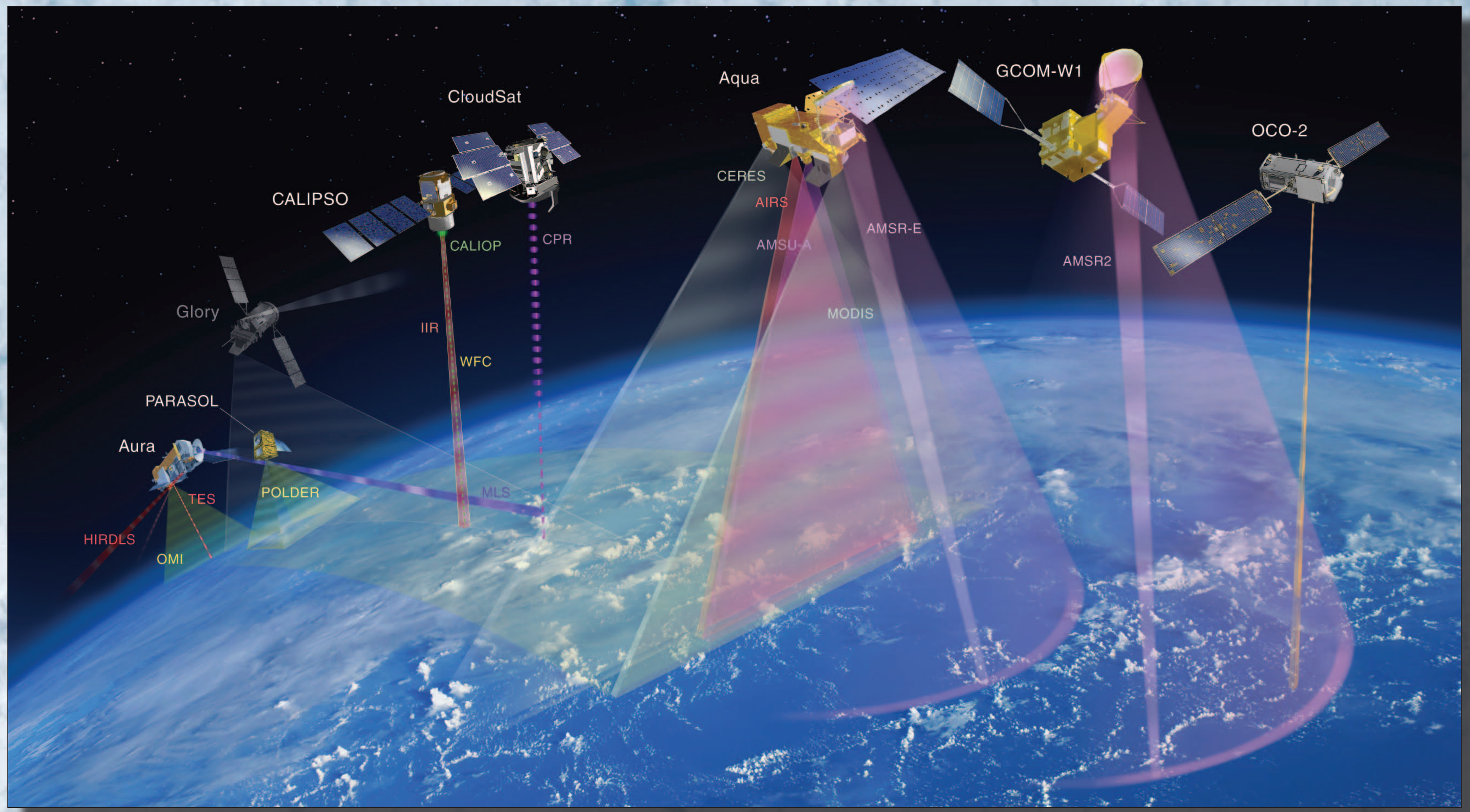
The A-Train

Constellation Flying for Understanding Earth

National Aeronautics and Space Administration

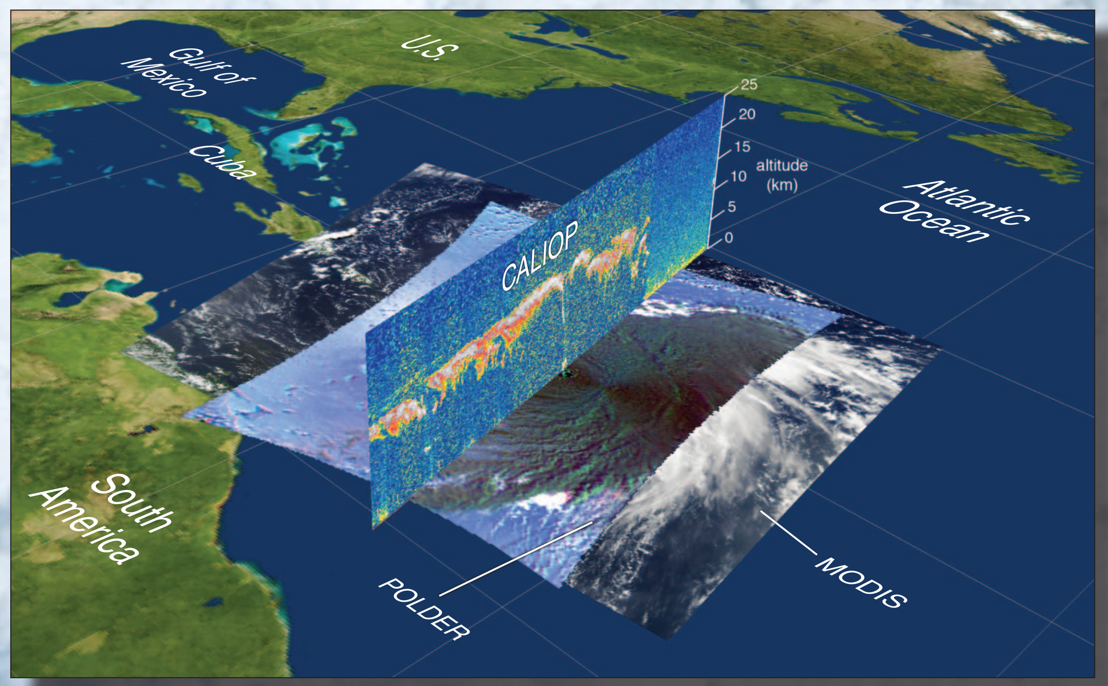
What is the A-Train?

NASA and its international partners operate several Earth-observing satellites that closely follow one after another along the same orbital “track.” This coordinated group of satellites, constituting a significant subset of NASA’s current operating major satellite missions, is called the *Afternoon Constellation*, or the *A-Train*, for short. The satellites are in a polar orbit, crossing the equator at about 1:30 p.m. local time, within seconds to minutes of each other. This allows near-simultaneous observations of a wide variety of parameters to aid the scientific community in advancing our knowledge of Earth System Science and applying this knowledge for the benefit of society.



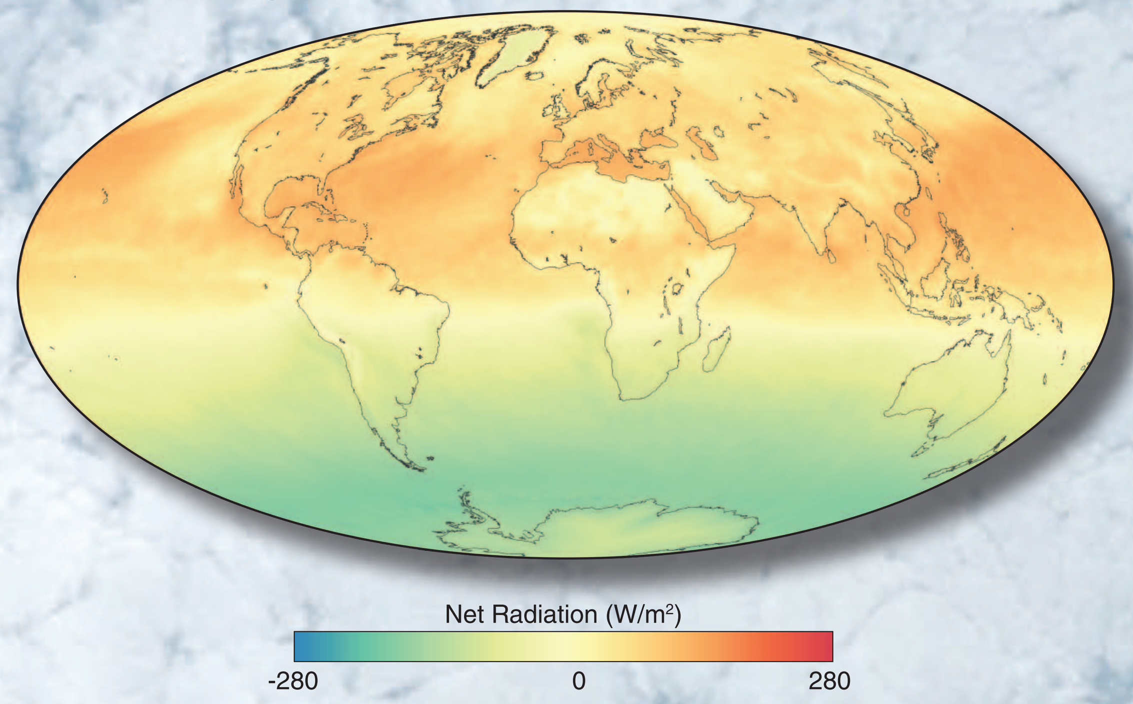
As depicted here, by about 2014 the international Afternoon Constellation should include OCO-2, GCOM-W1, Aqua, CloudSat, CALIPSO, and Aura. (Glory was lost in a launch vehicle failure on March 4, 2011.) In December 2009, PARASOL began to leave the constellation; it will exit completely by 2012. The instruments on these precisely engineered satellites make almost simultaneous measurements of clouds, aerosols, atmospheric chemistry, and other elements critical to understanding Earth’s changing climate. The footprint of each of the A-Train’s instruments is shown: active instruments aboard CALIPSO/CALIOP and CloudSat/CPR are indicated with dashed lines. This illustration color-codes instrument swaths based on observed wavelength ranges. Microwaves (observed by both AMSRs, AMSU-A, CPR, MLS) are represented by red-purple to deep purple colors; solar wavelengths (POLDER, OMI, OCO-2), yellow; solar and infrared wavelengths (MODIS, CERES), gray; other infrared wavelengths (IIR, AIRS, TES, HIRDLS) are represented by reds.

Clouds and Weather



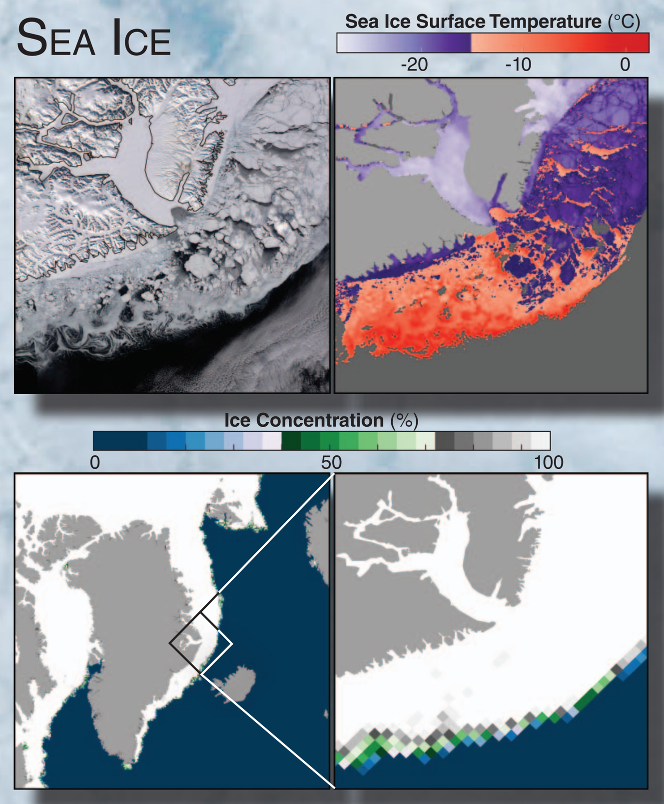
An image of Hurricane Bill as seen from the MODIS instrument (flying on Aqua) with cloud heights from the CALIOP lidar (on CALIPSO) on August 19, 2009. Superimposed over the MODIS image is the polarized reflected sunlight observed by POLDER (on PARASOL).

Net Radiation



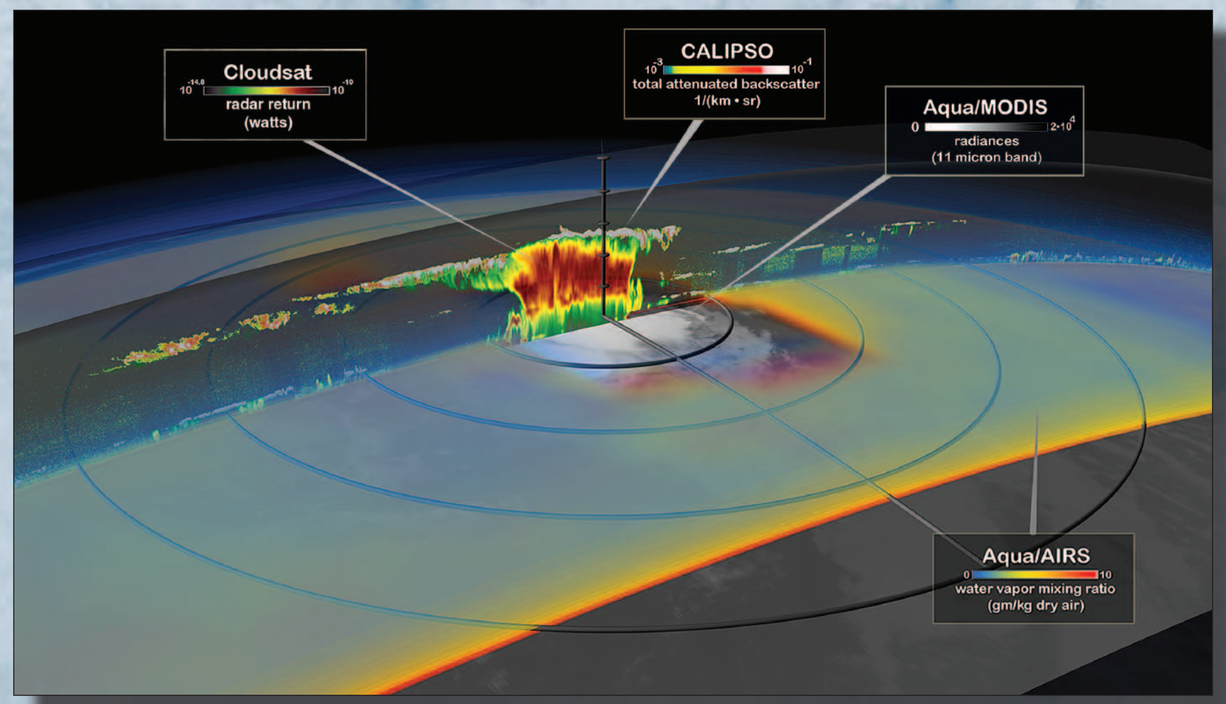
The above map shows net top-of-atmosphere radiation (difference between absorbed sunlight and emitted outgoing longwave radiation) from the Aqua/CERES instrument for July 2010. Positive values, indicating net warming, are found in the summertime (Northern Hemisphere). This is an example of synergy between A-Train instruments as CERES makes use of MODIS aerosol and cloud retrievals that are informed by CALIPSO and CloudSat observations.

Sea Ice



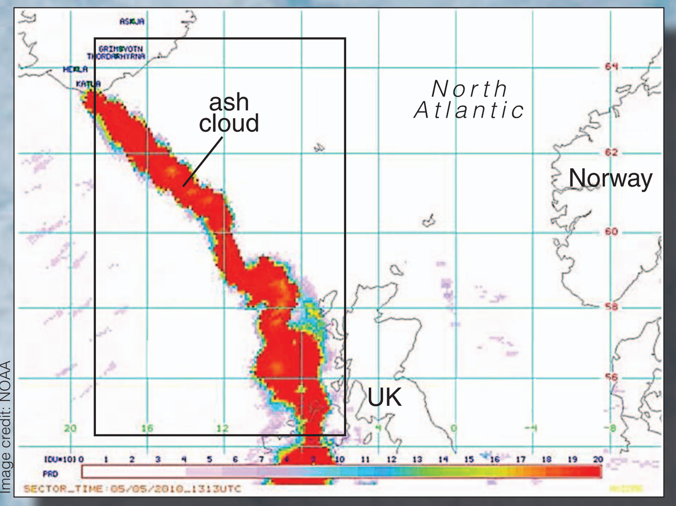
Images from Aqua of East Greenland, March 27, 2010. A MODIS image (upper left) shows glaciers and snow cover on land, and sea ice floes in the ocean. Ice-surface temperature (IST), derived from MODIS (upper right), increases roughly with decreasing sea ice concentration, derived from AMSR-E (lower right), toward the ice-water boundary.

Clouds and Weather

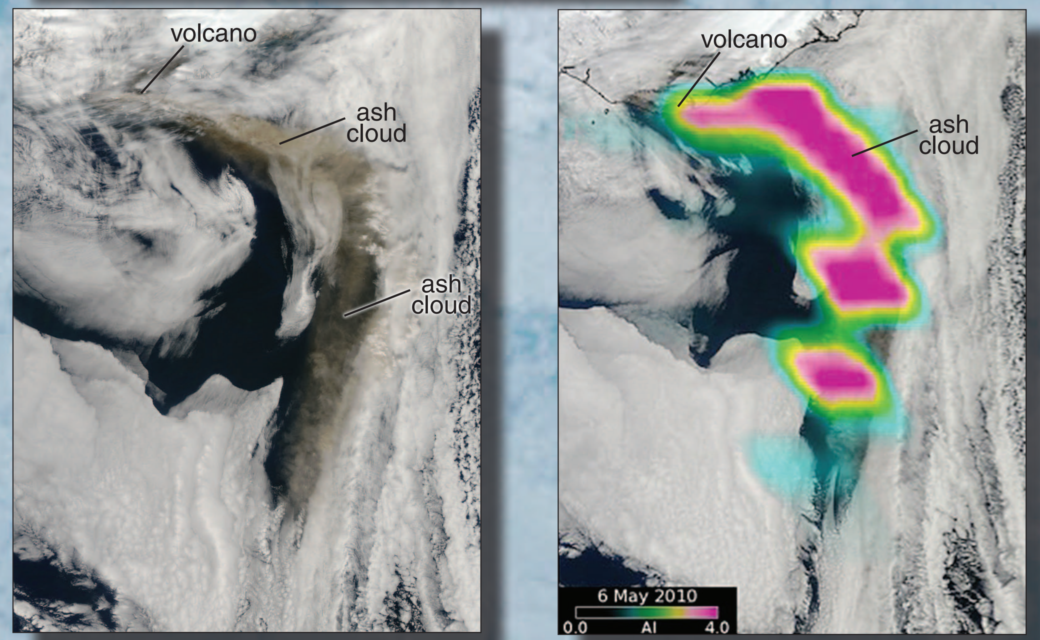


Tropical Storm Debby crossed the Central Atlantic on August 24, 2006 and was observed by four different A-Train instruments: Aqua/MODIS (in gray, center) shows an overview of the storm; Aqua/AIRS water vapor mixing ratio data are superimposed; and CloudSat’s radar (CPR) and CALIPSO’s lidar (CALIOP) show different types of information on a vertical slice through the storm’s center.

Atmospheric Chemistry

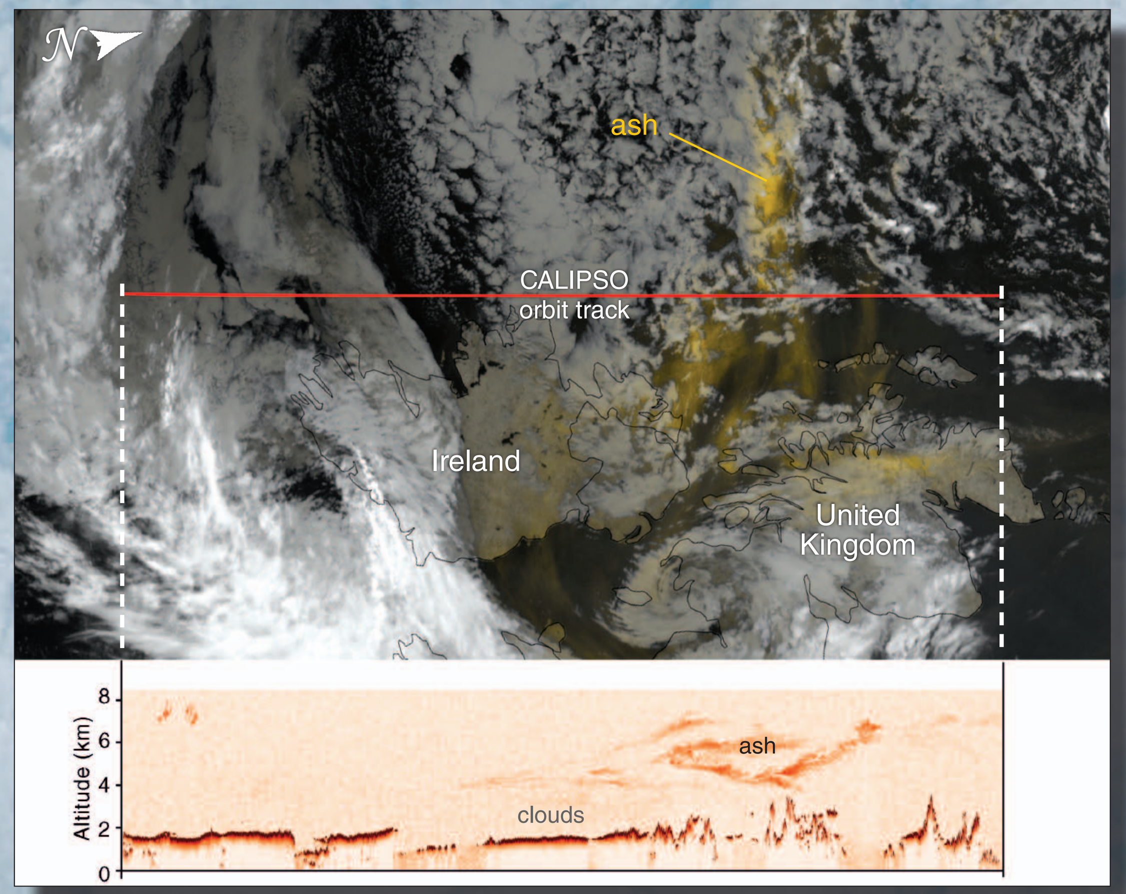


On May 5, 2010, Aura/OMI observed a sulfur dioxide (SO_2) plume from the eruption of Iceland’s Eyjafjallajökull volcano. Such a plume is an indicator of fresh volcanic ash clouds.



On May 6, 2010, Aqua/MODIS (left) and Aura/OMI (right) observed the volcano’s ash cloud. MODIS gives a “visible” picture of the ash cloud (brown). OMI measures aerosol concentration. Highest aerosol concentrations are in pink.

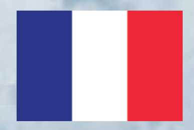
Aerosols



An aerosol-laden ash plume from the Eyjafjallajökull volcano in Iceland was observed from Aqua/MODIS (top image) and CALIPSO/CALIOP (bottom image) on May 16, 2010.





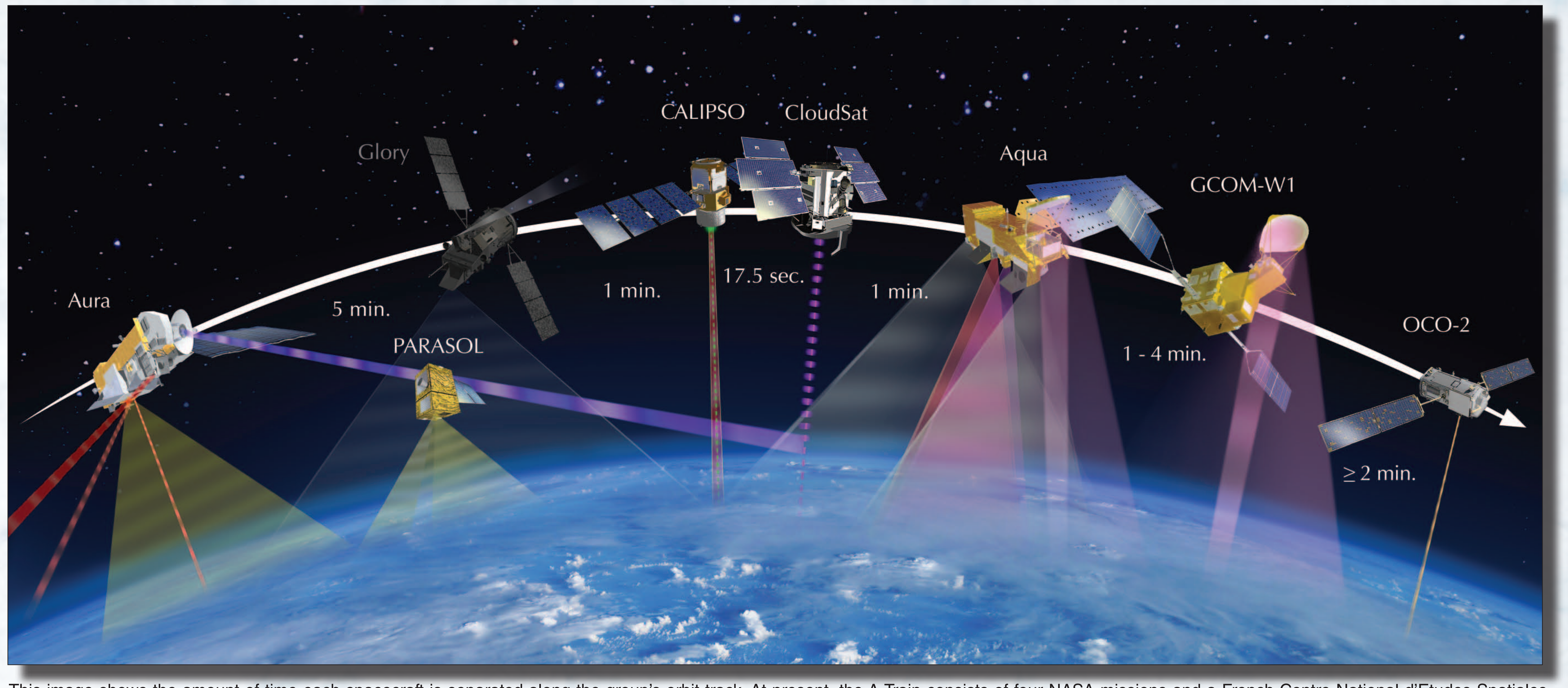



Taking the A-Train

A satellite constellation like the A-Train is composed of a number of satellites following one another along a "track" in space. While they aren't literally connected like railroad cars, precise engineering and planning—called *constellation flying*—allows for them to function as if they were "connected."

Constellation flying allows the instruments on all of the A-Train satellites to function as if they were on a large platform together. This means that scientists can use instruments on several different satellites in the constellation to study a particular atmospheric phenomenon of interest—e.g., clouds, aerosols, greenhouse gases—and learn more than they could have with any one satellite by itself.

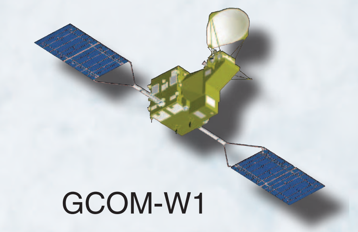
Combining data from these satellites enables scientists to gain a better understanding of a variety of Earth-system processes, including those relevant to climate. Data collected synchronously gives more-complete answers to important scientific questions than would be possible with satellite data collected at different times.



This image shows the amount of time each spacecraft is separated along the group's orbit track. At present, the A-Train consists of four NASA missions and a French Centre National d'Etudes Spatiales (CNES) mission flying in close proximity to one another: Aqua (launched in 2002), Aura (launched in 2004), the Cloud-Aerosol Lidar and Infrared Pathfinder Satellite Observations (CALIPSO) and CloudSat (launched together in 2006), and the French satellite mission, Polarization and Anisotropy of Reflectances for Atmospheric Science coupled with Observations from a Lidar (PARASOL, launched in 2005). By 2014 it should include the six missions shown along the white arrow above. PARASOL will have drifted out of the A-Train completely by 2012. Glory was lost in a launch vehicle failure on March 4, 2011.

National Aeronautics and Space Administration

Two New Satellites on Board: Bringing You a Better A-Train



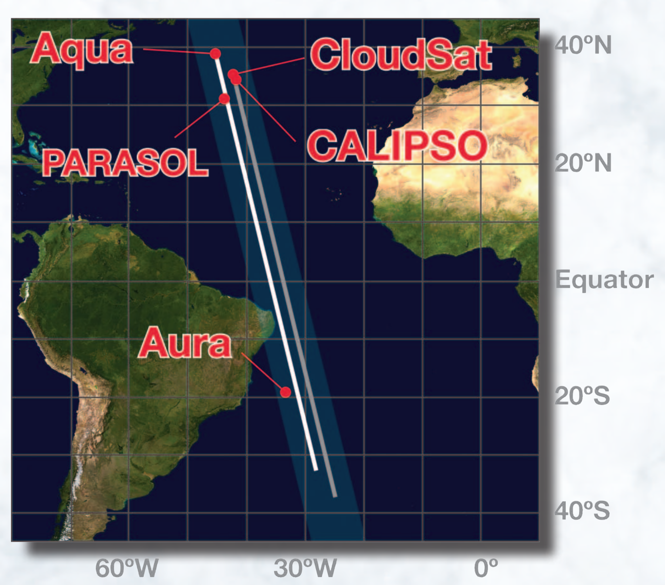
GCOM-W1

The Global Change Observation Mission (GCOM-W1), a mission from the Japan Aerospace Exploration Agency (JAXA), is scheduled to join the A-Train in early 2012. A second-generation Advanced Microwave Sensing Radiometer (AMSR2) will observe atmospheric and oceanic parameters (i.e., precipitation, sea surface temperature and wind speed, cloud liquid water, and column water vapor), sea ice concentrations and snow water equivalent, and surface wetness over land.

The second Orbiting Carbon Observatory (OCO-2) satellite will join the configuration in early 2013. It is NASA's first satellite dedicated to making full-column measurements of carbon dioxide (CO_2) with the sensitivity, resolution, and coverage needed to quantify surface sources and sinks of this important greenhouse gas.

OCO-2

The Benefits of Constellation Flying



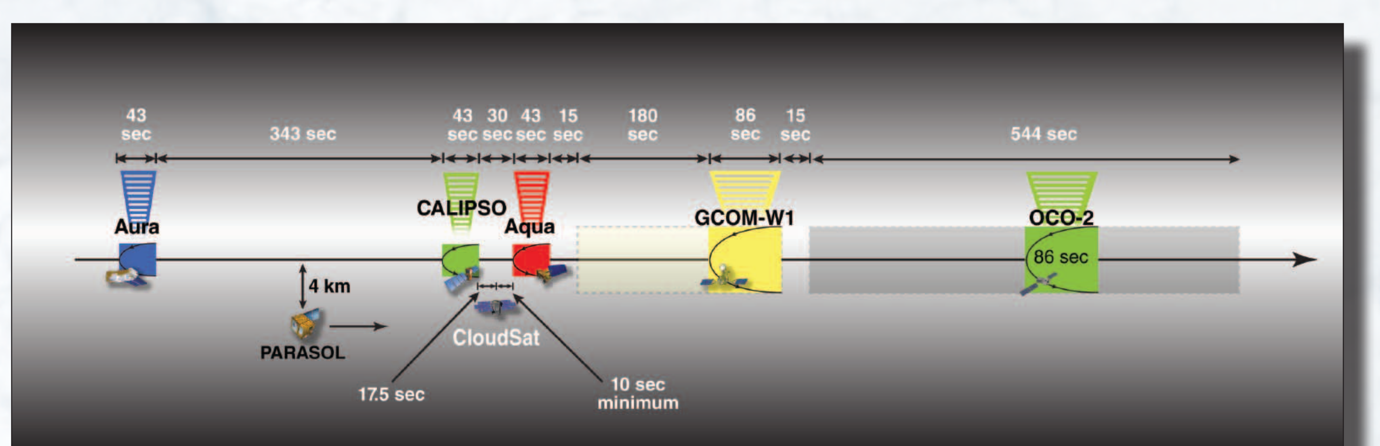
The A-Train is a series of satellites following each other in orbit. In order for multiple instruments to effectively observe the same Earth scene—and thereby obtain more data than could be provided by any one instrument—the instruments must view the scene within a short time period to prevent changes in observing conditions (especially true for clouds). [Read more in the sidebar, "Taking in the View"] Different satellites that carry these instruments must, therefore, fly closely together in a carefully planned and executed manner.

Science from the MODIS instrument on Aqua can be compromised by sun glint. Therefore, CloudSat and CALIPSO are positioned so that coincident MODIS views avoid this contaminating phenomenon. These two satellites are positioned 215 km on the side of Aqua's ground track that is opposite the sun; they must not lag Aqua by more than two minutes, and may never precede it. CloudSat has to maneuver in tandem with CALIPSO to maintain its position relative to Aqua. It must also maneuver independently to preserve its position no more than 15 seconds ahead of CALIPSO. Aura is positioned substantially behind the others, so its Microwave Limb Sounder (MLS) can view horizontally under the same portion of the atmosphere that Aqua is viewing from above.

There is a remarkable advantage to this precise constellation: At the expense of a slight temporal separation, constellation flying of multiple satellites simulates a single satellite that is hundreds of kilometers in size!

Constellation Flying: A Control Issue

The A-Train is a carefully planned constellation that allows for *synergy* between the missions. Synergy means that more information about the condition of Earth is obtained from combined observations than would be possible from the sum of the observations taken independently. However, in order for synergistic measurements to be successfully obtained, the constellation configuration has to be precisely aligned in time and space, with respect to each other and with respect to the planet below. This calls for ongoing coordinated maneuvering of the spacecrafts to keep them in a tight configuration.



The heart of constellation flying is the implementation of control boxes. Each satellite is allowed to drift within its respective control box (seen in the diagram above as colored boxes surrounding the satellites) until it approaches the boundary of its box. At that point the satellite must execute maneuvers to adjust its orbit. These maneuvers maintain the observing times and geometries of the instruments, but more importantly, they avoid potential collisions that would threaten the entire constellation by producing a debris field, not to mention the loss of synergistic data.

In the current A-Train configuration, Aqua is maintained inside a control box of ±21.5 seconds (about ±158 km at its orbital velocity). It makes precisely 233 complete orbits in 16 days. CloudSat flies in a smaller control box (not shown), 17.5±2.5 seconds ahead of CALIPSO. CALIPSO, in turn, is maintained in a ±21.5-second control box averaging 73 seconds behind Aqua (about 547 km). CALIPSO is never closer than 30 seconds (about 225 km) to Aqua. CloudSat is "formation flying" with CALIPSO, that is, CloudSat moves whenever CALIPSO moves. Similarly, PARASOL flew about 131 seconds behind Aqua before its orbit was lowered in late 2009. Once launched, GCOM-W1 will be maintained in a ±43-second control box that is between 15 and 195 seconds in front on Aqua's control box. Later, OCO-2 will join the A-Train and also be maintained in a ±43-second control box that is at least 15 seconds in front on GCOM-W1's control box. And, finally, Aura flies about 459 seconds behind Aqua.

The Instruments on Board

The A-Train platforms and their instrument manifests, described below, work together to produce a comprehensive picture of the Earth system. Most are *passive* instruments that detect radiation emitted or reflected from a target. Each instrument detects radiation in one or more *spectral bands*—a range of microwave, infrared, visible, or ultraviolet wavelengths. Some bands are relatively broad (as for imaging instruments), while others are extremely narrow (as for several thermal infrared-detecting instruments). The instruments cover a variety of different viewing angles and *polarizations* that allow light from specific directions and orientations, respectively, to be measured.

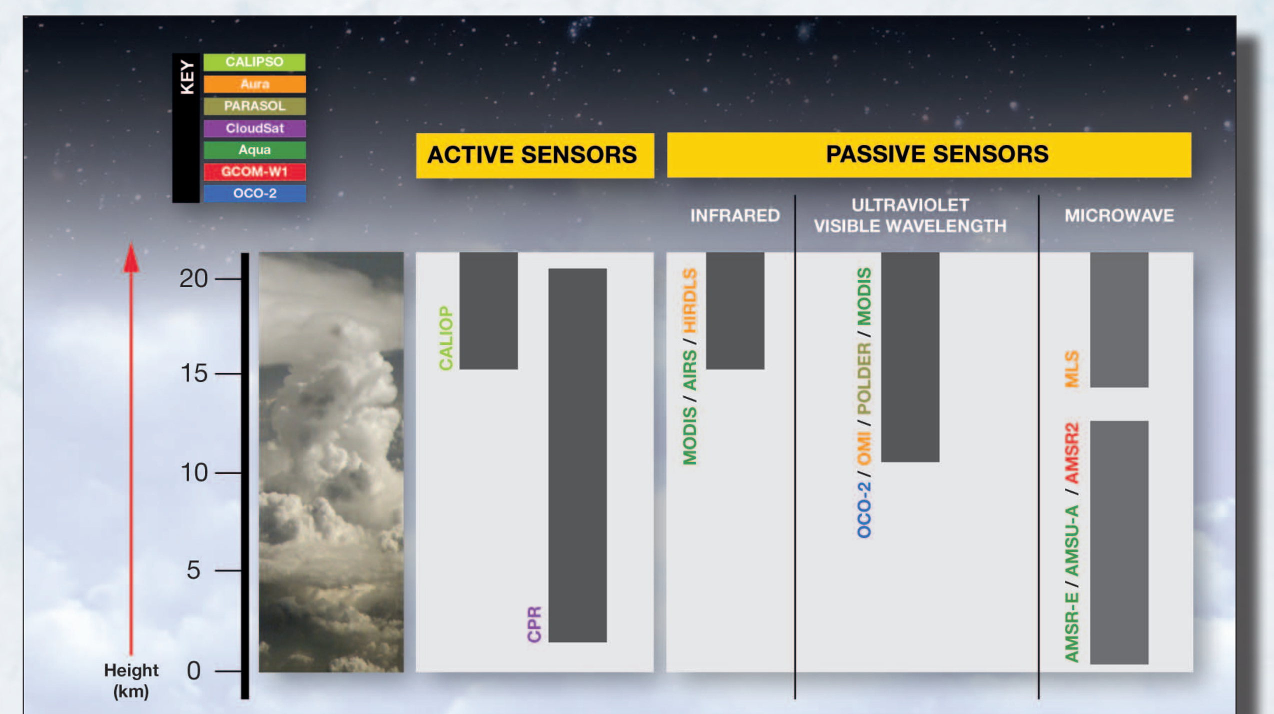
In contrast, CloudSat's radar and CALIPSO's lidar are *active* instruments that emit an energy pulse (microwave and visible radiation, respectively) and measure the energy reflected or backscattered to the sensor. Scientists study these *return pulses* and use them to create three-dimensional profiles of clouds and aerosols.

Satellite	Instrument		Measurement
Aura	HIRDLS	High Resolution Dynamics Limb Sounder	Temperature and composition of the upper troposphere, stratosphere, and mesosphere; aerosol extinction and cloud height
	MLS	Microwave Limb Sounder	Temperature and composition of the upper troposphere and stratosphere; upper tropospheric cloud ice
	OMI	Ozone Monitoring Instrument	Total column ozone, nitrogen dioxide, sulfur dioxide, formaldehyde, bromine monoxide, aerosol absorption, and cloud centroid pressure
	TES	Tropospheric Emission Spectrometer	Temperature, ozone, carbon monoxide, and water vapor profiles from the surface to lower stratosphere
PARASOL	POLDER	POLarization and Directionality of Earth's Reflectances	Polarized light measurements of clouds and aerosols
CALIPSO	CALIOP	Cloud-Aerosol Lidar with Orthogonal Polarization	High-resolution vertical profiles of aerosols and clouds
	IIR	Imaging Infrared Radiometer	Nadir-viewing, non-scanning imager
	WFC	Wide Field Camera	Fixed, nadir-viewing imager with a single spectral channel covering a portion of the visible (620–670 nm) region of the spectrum to match Band 1 of the MODIS instrument on Aqua (see below)
CloudSat	CPR	Cloud Profiling Radar	Vertical profiles of water amount measured by backscattered radar signals from clouds
Aqua	AIRS	Atmospheric Infrared Sounder	Highly accurate temperature profiles within the atmosphere
	AMSR-E	Advanced Microwave Scanning Radiometer for Earth Observing System (EOS)	Precipitation rate, cloud water, water vapor, sea-surface winds, sea-surface temperatures, ice, snow, and soil moisture
	AMSU-A	Advanced Microwave Sounding Unit-A	Temperature profiles in the upper atmosphere, especially in the stratosphere
	CERES	Cloud's and Earth's Radiant Energy System	Solar-reflected and Earth-emitted radiation; cloud properties (altitude, thickness, and size of the cloud particles)
	HSB	Humidity Sounder for Brazil	Humidity profiles throughout the atmosphere **(Inoperative since 2003)**
	MODIS	MODerate-resolution Imaging Spectroradiometer	Vegetation, land surface cover, ocean chlorophyll fluorescence, cloud and aerosol properties, fire occurrence, land snow cover, and sea ice cover
GCOM-W1	AMSR2	Advanced Microwave Scanning Radiometer, second generation	Enhanced understanding of water in Earth's climate system and the global water cycle, and of additional components of Earth's climate system and their interactions
OCO-2	Three high-resolution grating spectrometers		Full-column measurements of CO_2

Seeing the World Through Different Glasses

Human eyes only see a small portion of the electromagnetic spectrum. Instruments on orbiting satellites expand our ability to "see" into other portions of the electromagnetic spectrum, and thereby give us a broader and deeper view into our environment. This is done with both active and passive sensors, as described in the panel, "The Instruments on Board."

The A-Train is equipped with a variety of *passive* and *active* remote-sensing instruments that allow it to "see" far more than our human eyes would from the same vantage point. Some A-Train sensors have a larger *footprint*—scanning a much larger spatial area than others. Some have higher *resolution*—they can "see" the target in greater detail than others. The illustration below highlights the difference in the way the A-Train sensors observe clouds.



The *active sensors* (i.e., CPR and CALIOP) emit pencil-thin pulses of energy that slice through the atmosphere, and strike a target. The *return pulse* of energy is analyzed to produce a very high-resolution view of a very small area. For CALIOP, the pulse is visible light, which is very sensitive to aerosol layers and high, thin clouds, but can't penetrate the atmosphere when thicker clouds are present. For CPR, the pulse is microwave energy, which can easily penetrate lower and thicker clouds and is sensitive to 90% of all clouds.

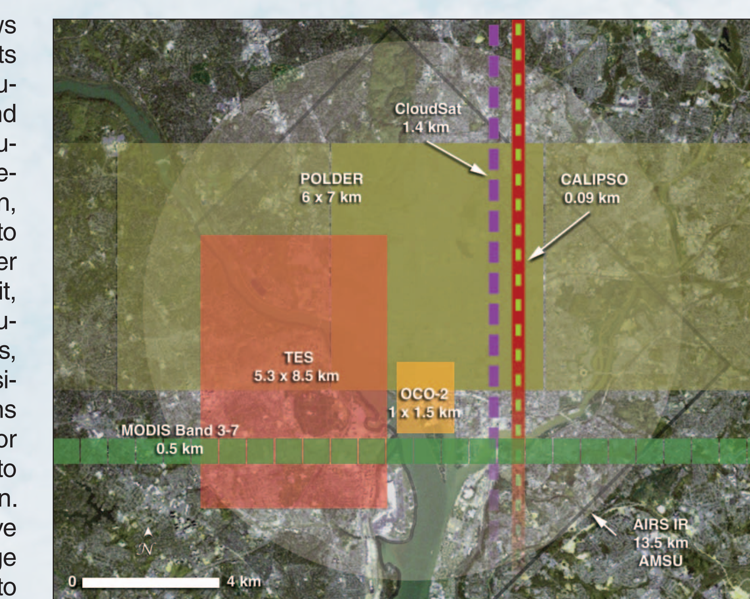
The *passive sensors* don't emit energy; they "see" reflected sunlight in the visible and ultraviolet wavelengths, and heat (infrared, or IR) that is both reflected and emitted from Earth's atmosphere and surface. They provide wider, more global coverage, allowing for snapshots of different layers of the atmosphere. Each instrument detects certain wavelengths of infrared, visible, ultraviolet, or microwave energy. It turns out that each of these types of radiation offers strengths and weaknesses when it comes to observing the atmosphere. IR sensors detect the heat released from whatever surface they observe, but can't penetrate thick cloud layers. (Note that HIRDLS, an *IR limb sounder,* looks sideways across the atmosphere and is more sensitive to very high, thin clouds.) Ultraviolet and visible sensors (e.g., MODIS) are able to probe deeper into clouds than IR sensors, but not all the way to the surface. Microwave sensors (e.g., AMSR, AMSU) can "see" the whole atmosphere—even when it's cloudy. (MLS is a bit different; it is a limb sounder that looks across the atmosphere and detects frozen water in the tops of towering clouds.)

The challenges of combining the measurements are considerable, but when all these perspectives are successfully brought together, what emerges is one of the most complete pictures of the Earth system ever obtained. This new information is helping to improve our understanding of the individual elements that compose the Earth system and how these elements interact to influence Earth's climate.

Taking in the View

The two illustrations shown here illustrate a few of the different A-Train instrument footprints and also highlight the challenge of constellation flying discussed earlier.

The map at left shows some of the A-Train satellites as if looking down on the entire constellation from orbit. The satellites that make up the A-Train travel from south to north (bottom to top in this image). The satellites near the front of the A-Train—i.e., Aqua, CloudSat, CALIPSO, PARASOL—are positioned in a close grouping (top), while Aura brings up the rear of the constellation, positioned much further back (bottom). The colorful bars across each satellite illustrate the scanning swath of several instruments. From this remote perspective, the instruments with smaller footprints are barely visible. The table in this illustration lists each satellite, selected instruments, and the width of each swath in kilometers.



The image at right shows the overlapping footprints of several A-Train instruments (colors correspond to the table above) superimposed on a close-up image of Washington, DC. The purpose is to give a sense of how, over the course of an orbit, the swath of each instrument overlaps the others, allowing for the nearly simultaneous observations of the same location or event that are crucial to the science of the A-Train. This close-up perspective also brings the challenge of constellation flying into sharper focus. In order to successfully overlap science measurements from different A-Train instruments, each with varying footprints and resolutions, each member of the A-Train must strictly maintain its position in the constellation as described above.

Mission Data: The A-Train Data Depot and ICARE

Each A-Train instrument has a team of supporting scientists and engineers that has established an infrastructure for data production, archiving, and distribution of Level-1 and higher-order products. Details are available at the mission and/or instrument web sites. In addition, cross-instrument A-Train data distribution systems that address merged data and visualization capabilities, have been developed as described below.

The A-Train Data Depot (ATDD) provides easy on-line data access and services for science, applications, and educational use, so that users can obtain exactly the data they need. The portal has been developed to process, archive, allow access to, visualize, analyze, and correlate distributed atmospheric measurements from A-Train instruments. (http://disc.sci.gsfc.nasa.gov/atdd)

The Cloud-Aerosol-Water-Radiation Interactions (ICARE) Thematic Center was created in 2003 by the Centre National d'Etudes Spatiales (CNES), the Centre National de la Recherche Scientifique (CNRS), the Nord-Pas-De-Calais Regional Council, and the University of Lille, to provide various services to support the research community in fields related to atmospheric research, such as aerosols, clouds, radiation, the water cycle, and their interactions. (www.icare.univ-lille1.fr)

The A-Train flew over the super-typhoon Choi-wan on September 15, 2009. This particular image includes data from four A-Train sensors: CloudSat/CPR, Aura/MLS, Aqua/MODIS, and Aqua/AMSR-E.

Data have already demonstrated that the potential for scientific discovery dramatically increases when the A-Train's diverse sensors observe the same phenomena at virtually the same time (see below left).